ANTARCTIC GEOLOGY AND SOLID-EARTH GEOPHYSICS

Guidelines for U.S. Program Planning

1973-1983

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Panel on Geology and Solid Earth Geophysics
Committee on Polar Research
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1974

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The members of the committee selected to undertake this project and prepare this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. Responsibility for the detailed aspects of this report rests with that committee.

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Foreword

The Committee on Polar Research (CPR) was asked by the National Science Foundation (NSF) to undertake a series of discipline-oriented studies on antarctic research. Each was to include a 10-year plan of investigation that was compatible with anticipated logistic, operational, and fiscal constraints. As background, the Committee was provided with a variety of operational and logistical alternatives, along with their estimated costs, that might be developed over the next 10 to 20 years.

In his letter to the Committee, Joseph O. Fletcher, Head of NSF's Office of Polar Programs, stated:

> Our objective in Antarctica is to support the most fruitful scientific program. Our long range operational requirements and logistic plans must be based on clear delineation of scientific problems and identification of the most promising approaches for solving them. We need your help to do this.
>
> For example, a few operational alternatives that depend on evaluation of scientific needs are:
>
> 1. Shall we continue to develop facilities at McMurdo Sound and Christchurch, our bases of operations during the past 15 years, or will future scientific needs call for operational capabilities in areas too far from McMurdo for operational support (such as the Weddell Sea)? If so, we need to start now to prepare for these needs. (For example, the location of Siple Station is determined by its conjugacy to a Canadian station and the proximity of their magnetic field line to the plasmapause—but Siple Station is closer to South America than to McMurdo—where will the next conjugate pair be?)
> 2. Should we close down the facilities in the Antarctic Peninsula (Palmer Station and R/V *Hero*), continue activities at the present level, or undertake more ambitious activities there? (R/V *Hero* could probably be more intensively utilized—especially in winter.)
> 3. Should we invest in a refit and modernization of the USNS *Eltanin* in 1974 or retire her?
> 4. What will be our requirements for icebreaker support in 1980? (This is a question of current urgency.)
> 5. Should we continue a pattern of intense summer operations and winter hibernation or develop capabilities for all season operations? What kind of operations? Why?

6. Will our future scientific needs be met by fixed stations and present methods of field party support, or should we actively develop mobile or transportable laboratories, employing vehicles such as the hovercraft?

7. With our operational capability centered at the Ross Sea, a number of programs have developed that are directly related to the presence of the large ice shelf: mass budget and deformation, ice shelf drilling, sub-shelf heat and mass budget, sub-ice-shelf biota, bottom water formation, sediment cores. Do we want eventually to continue these studies in the Ronne Ice Shelf region? If so, when and where?

In accepting this challenge, the Committee was mindful that the cost of logistic support for implementing polar research is exceptionally high because of the remoteness, inaccessibility, extreme cold, and extended periods of daylight and darkness. Accordingly, the Committee gave considerable emphasis to the acquisition of useful data by automatic stations, to include unmanned geophysical observatories, buoys, aircraft, balloons, rockets, and space vehicles. In developing its reports, the Committee looked upon the antarctic region as an integral part of total global environment and, whenever possible, related its recommendations to the objectives of on-going international worldwide research programs such as the Global Atmospheric Research Program (GARP), the International Decade of Oceanic Exploration (IDOE), and the Deep Sea Drilling Project (DSDP).

The Committee called on each of its discipline-oriented panels to prepare studies as proposed. The outcome is a series of reports, each of which focused on one of the particular disciplines: glaciology, oceanography, meteorology and climatology, geology and solid-earth geophysics, upper-atmosphere physics, and biology. Outside experts were called in as required, and each of the reports was reviewed by concerned groups within the National Academy of Sciences and the National Research Council. This is one of the series of such reports. The Committee intends to review and update these studies periodically, as advances and developments dictate. This approach deviates somewhat from that taken in developing the report, *Polar Research: A Survey* (National Academy of Sciences, Washington, D.C., 1970), which was a more general study that included both polar regions and covered a somewhat shorter time scale.

The Committee on Polar Research is supported by a contract from the Office of Polar Programs, National Science Foundation.

James H. Zumberge, *Chairman*
Committee on Polar Research

Preface

This report is an attempt by the Panel on Geology and Solid Earth Geophysics to assess the principal problems of antarctic solid-earth science over the next decade, to evaluate their importance in relation not only to the south polar regions but also to the earth as a whole, and to suggest ways and a priority ordering for undertaking their solutions. In examining these problems, we have paid minimal attention to specific logistical requirements, although our thinking was conditioned by the realities of antarctic operations.

The Study Group responsible for preparing this document was composed of Charles R. Bentley, Colin B. Bull, Ian W. D. Dalziel, David Elliot, Arthur B. Ford, and Robert H. Rutford; Mortimer D. Turner provided liaison with the National Science Foundation's Office of Polar Programs. The Study Group met in Madison, Wisconsin, to draw up the outline of this report and issue a draft, which was then reviewed by the entire Panel. Contributions from George Gryc and E. Fred Roots were particularly valuable.

Charles R. Bentley, *Chairman*
Panel on Geology and Solid Earth Geophysics

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1

Introduction

The fundamental purpose of geology and solid-earth geophysics is to determine the composition, structure, and history of the earth. This purpose has a practical objective, for the knowledge obtained is necessary to the location, assessment, and optimum use of the natural resources of the planet. Basic to that purpose is an understanding of the dynamic processes that mold the features of the earth and control the concentration and emplacement of mineral deposits. Modern concepts of plate tectonics provide a unifying framework for understanding earth dynamics and bring into focus the need for a global approach to the problems of geodynamics. Some of these problems can best be resolved in Antarctica.

The principal objectives of geological and geophysical research in Antarctica are twofold: (a) to determine the geological framework and history, which is a prerequisite to understanding the physical features and evolution of the continent and the surrounding ocean floor and evaluating their resource potential; and (b) to determine the role of the south polar regions in global geodynamics and planetary history.

As mineral resources become depleted in more accessible lands, there will be increasing need for accurate assessment of the mineral potential of the Antarctic Continent and its adjoining shelves and deep ocean floors. Close similarity of Antarctica's geology to that of mineral-rich provinces of other southern continents indicates the likelihood of large resources in Antarctica, although economic factors presently preclude their exploitation. Commercial exploration has not yet been undertaken within the Antarctic Treaty area, and therefore the present knowledge of resources is a by-product of the scientific explorations that have been carried out by many nations for many years, with public dissemination of the information. However, this knowledge is inadequate for an accurate resource appraisal, and the continuation of basic earth-science research is necessary to provide the geologic background data needed to assess the potential resources of the continent. Regardless of the future control of the Antarctic Treaty area and future decisions regarding commercial exploitation, a sound assessment of potential resources is essential so that we will be able to deal realistically with practical and policy questions that will soon arise.

Subsidiary, but nonetheless important, objectives of antarctic earth-science research are to delineate the history of the antarctic ice sheet as recorded in surficial deposits beneath the ice and around its margins and to contribute to the understanding of the development of antarctic terrestrial and marine life. The past behavior of the ice is intimately related to paleoclimates, and it is only by understanding the dynamic interrelationship between atmosphere, ocean, and ice that predictions about climate and the physical and biological environment of the southern polar regions will become possible.

In evaluating the importance of antarctic research projects, it is essential to keep in mind that the basic framework of antarctic earth structure is still poorly known. Gaps in our basic knowledge can best be filled by widespread, single-purpose, and commonly exploratory studies. Consequently, a major part of the U.S. program must continue to comprise relatively small, scattered projects–much of antarctic geological research is not compatible with the large-scale, acronymic "project" approach that can be applied so effectively to the development of knowledge in depth in other disciplines, such as oceanography, glaciology, and solar-terrestrial physics. Failure to recognize this fact could seriously impair the effectiveness of the U.S. earth-science research program over the next decade.

2

Particular Concerns and Requirements

Before considering the major research problems of antarctic geology and solid-earth geophysics, we wish to point out several important requirements of special concern to earth-science studies in Antarctica and to the plans for completing present and future projects and evaluating the resource potential of the continent.

ENVIRONMENTAL SAFEGUARDS

The Antarctic Treaty provides environmental safeguards for activities associated with biological studies but none for activities related to geological and geophysical exploration. Past earth-science studies created little hazard, but future studies that are on a larger scale and involve drilling and seismic studies, particularly in offshore areas, will have greater hazard potential. Some will introduce problems of solid waste disposal to inland Antarctica. Geological studies tend to concentrate on the limited ice-free terrestrial areas, which are also areas of greatest terrestrial biological activity and which are highly vulnerable to environmental damage. Interdisciplinary research on environmental effects of oil pollution in cold, ice-covered seas should be encouraged. Procedures must be developed and followed that will ensure protection of the antarctic environment in all future explorations.

TOPOGRAPHIC MAPPING

The U.S. Geological Survey 1:250,000 Reconnaissance Series of topographic maps must be completed for West Antarctica and the Transantarctic Mountains. In particular, the maps of the areas for which ground control is currently available should be completed as soon as possible. The maps of the coastal portion of West Antarctica from Cape Colbeck to the base of the Antarctic Peninsula should receive highest priority, as the reconnaissance geologic study of most of this area has been completed.

The 1:500,000 Sketch Map Series should be continued where required, and maps at this scale should be available to field parties working in areas not covered by other maps of suitable scale. This map series should not be considered as an adequate substitute for the 1:250,000 series, and resources should not be allocated to the Sketch Map Series at the expense of progress on the Reconnaissance Series.

REGIONAL GEOLOGICAL AND GEOPHYSICAL SURVEYING

To understand the structure and history of the Antarctic Continent, it is necessary to complete the reconnaissance mapping (i.e., on a scale of 1:250,000 or larger) of all areas of exposed bedrock. It is desirable and generally feasible to include both a geological and geophysical program in the initial study of an unknown area.

Attention of the U.S. program should be directed toward filling in any remaining gaps in the following regions, in order of priority:

1. Victoria Land
2. Marie Byrd Land/Ellsworth Land
3. Transantarctic Mountains northwestward from the Horlick Mountains
4. Scotia Arc
5. Transantarctic Mountains northeastward from the Thiel Mountains
6. Antarctic Peninsula

STATESIDE ANALYSES

The enduring result of geological and geophysical field studies is the published record. The U.S. program to date has emphasized field activities but has been lacking in published final reports. Among the reasons for this situation are (a) the absence of the topographic maps needed for the construction of geologic maps, (b) a shortage of financial support for work back home after returning from the field, and (c) the difficulty in arranging for the publication of basic monographs on regional geology and geophysics. A great deal of work is necessary in order to follow up and publish the results of one field season. Publication is costly because many reports are lengthy and most require colored geologic maps. These published reports and maps, and the laboratory analyses on which they are based, clearly deserve more support and encouragement than they have received so far.

REMOTE SENSING

A good regional knowledge of the configuration of the bedrock surface in Antarctica is essential to the interpolation of geologic structures between sparse outcrops. Continuous radio-echo profiling from the air is now almost routine and is capable of sounding most of the ice sheet. The radio-echo-sounding program should therefore be emphasized until the regional mapping of the bedrock surface is complete. Our recommended priority ordering of the regions is as follows:

1. Ross Sea drainage basin, Marie Byrd Land, and the "90° W Ridge"
2. Weddell Sea drainage basin
3. East Antarctica

Remote sensing should not be limited to radio-echo sounding. An aeromagnetic survey of the continent would be particularly valuable because it would make it possible to estimate the thickness of sedimentary rock overlying crystalline basement and to identify regions of volcanic rock beneath the ice. Sometime in the future, airborne gravity measurements should become feasible. A systematic gravity survey, combined with a map of ice thickness, would tell us much about problems such as the response of the earth's crust and mantle to the superimposed load of ice, the geologic significance of areas of broad gravity anomalies, the cause of the present uplift along the coastal periphery of East Antarctica, the delineation of the crustal provinces of East and West Antarctica, and the nature of the boundary between those provinces.

CORE DRILLING INTO BEDROCK BENEATH THE ICE

Plans for glaciological work in the next decade include core drilling through the ice sheet at a number of places in both East and West Antarctica. Valuable geological and geophysical information can be gained at a modest expense by extending these cores a short distance into the underlying bedrock.

Antarctica remains the only continent lacking data on geothermal flux rates. Temperature measurements in a 100-m borehole beneath a thick ice sheet, along with determinations of thermal diffusivity of the rock, could readily give this information. Most of the deductions of the physical conditions at the base of the ice sheet depend on an assumed flux rate, and, although determinations could not be expected at very many sites, the scientific value of these few measurements would be high.

Our direct knowledge of rock types in Antarctica is confined to the regions of exposed rocks, which comprise less than 5 percent of the total surface area. Information on the lithology of the bedrock underlying different parts of the ice sheet, at even a few sites, would therefore be of great help in interpreting geophysical data in order to better define the geological provinces of the continent. Furthermore, our knowledge of the material and conditions at the base of ice sheets is scanty, so core drilling to determine the thickness of glacial drift, the weathering of the material, and the particle-size distribution would be of great interest.

NEW TECHNIQUES

Support should be provided for the evaluation of the applicability to antarctic research of promising new geophysical methods, such as microearthquake recording to search for low-level seismicity in regions of suspected tectonic activity (see also the section on Seismicity in Chapter 4), the use of mortars or other devices to generate high-energy shear waves for seismic exploration, and magnetotelluric studies to provide information on the electrical conductivity in the earth, thus adding a new dimension to the examination of crustal and mantle structure. Unmanned geophysical observatories should be utilized to maximum advantage for solid-earth studies. The applications of satellite techniques of remote sensing and accurate positioning to antarctic mapping and to a possible determination of lateral displacements between Antarctica and adjacent continents should be examined. Furthermore, new methods and techniques whose applicability to antarctic problems are not currently recognized must be anticipated.

3

Intercontinental and Intracontinental Relationships

Alexandre du Toit pointed out over 30 years ago that in the geology of Antarctica lay the key to the concept of a southern supercontinent, Gondwanaland, that he believed to have existed before the most recent episode of continental drift in the Mesozoic and Cenozoic. In light of the present concepts of sea-floor spreading and plate tectonics, and the growing realization that knowledge of *all* the continents is vital for analysis of driving mechanisms, it is now, more than ever, essential to consider the relationship of Antarctica's geologic history and structure to that of the surrounding ocean basins and formerly contiguous continents.

The geologic relations within the continent are also important, because it now appears that the present continental masses have not always acted as entities—East and West Antarctica, for example, may have moved relative to one another, even splitting apart and rejoining, during the fragmentation of Gondwanaland.

PRESENT CONTINENTAL MARGINS

The margins of a continent at any one time are either tectonically passive or tectonically active. The margins of East Antarctica at the present time are passive, being essentially undeformed by tectonic processes since the fragmentation of Gondwanaland (although substantial uplift has occurred in some places). West Antarctica, on the other hand, has been modified since then by tectonic processes such as those characteristic of the western (Andean) margin of South America today. As this modification took place during the Mesozoic–Cenozoic period of sea-floor spreading and is still going on in the Antarctic Peninsula, West Antarctica can be considered as an active margin of the present continent.

PASSIVE CONTINENTAL MARGINS

The principal geologic problems of passive continental margins are to understand the cause, mechanism, and timing of the original continental rifting and fragmentation and to elucidate the subsequent continental separation, thereby leading to a reconstruction of the predrift continent.

By far the most important study still to be undertaken is marine geophysical work in the region between Antarctica and Africa, i.e., the uncompleted portion of USNS *Eltanin*'s circuit of Antarctica. Not only is the work in this region important for antarctic geology and geophysics, it is also crucial for global tectonic considerations. The South Atlantic is one of the most poorly known oceanic areas, but few ships are capable of undertaking detailed research work there. Every possible effort should be made to restore the *Eltanin* to service.

Areas of special interest should be studied in more detail after the reconnaissance work has been completed. Examples of problems include the following:

Depth to Basement of the Antarctic Continental Margin According to present plate-tectonic theory, an initial rift valley such as the Red Sea is usually formed when continents split apart. If the rift is not destroyed by later subduction, it should remain at the margin. Accurate knowledge of the morphology of continental margins is necessary for reconstructing predrift continental configurations such as that of Gondwanaland.

Kerguelen Plateau–Enderby Land There is some evidence that the sea floor off Wilkes Land is older than that along the eastern margin of the Kerguelen Plateau. This suggests that the Kerguelen Plateau may have been attached to Australia during the early stages of the breakup of Gondwanaland. If so, the crust to the west of Kerguelen could be very old; it should be examined in further detail.

The antarctic igneous rocks that might be associated with the fragmentation of Gondwanaland, such as the Ferrar dolerites, the Dufek Massif, and the late-Jurassic acidic volcanics of the Antarctic Peninsula, should be subjected to more detailed petrologic, geochemical, and isotopic study. They represent a major part of one of the largest continental igneous provinces in the world, which includes the Karroo dolerites in Africa and the Tobifera acidic volcanics in South America. Their origin appears to be closely tied to the rifting of Gondwanaland.

Geologic studies (including regional mapping) of the East Antarctic craton in Queen Maud Land and Enderby Land are also important but should be undertaken only when logistic support is available for other reasons. It is uncertain how much information providing evidence of the correlation between Antarctica, Africa, and India would be obtained, and other nations (Norway, Belgium, the Soviet Union, South Africa) have active mapping programs in the area.

ACTIVE CONTINENTAL MARGINS

Study of the world's tectonically active continental margins yields crucial information on the mechanics of mountain building and the history of Mesozoic–Cenozoic ocean-floor–continent interaction. The origin of a number of important suites of rocks, most notably granitic batholiths and andesites, and the causes of earthquakes are two other significant problems to which the resulting data are relevant.

The continental margin of West Antarctica that extends from Marie Byrd Land through the Antarctic Peninsula, and its connection around the Scotia Arc into South America, has been tectonically active throughout Mesozoic and Cenozoic time. The Antarctic Peninsula is an important locality for study, for it appears to represent the deep-seated roots of a former mountain range like the Central Andes of today, where there is intense volcanism but relatively little compressive deformation. (It should be noted that this is the tectonic environment in which the prophyry copper deposits of Chile were formed. "Shows" of copper are common in the Antarctic Peninsula and the islands of the Scotia Arc.) The rocks of West Antarctica may reflect the history of the Pacific Ocean basin against which they abut.

Thus there are global as well as regional reasons to study the geology of West Antarctica, the Antarctic Peninsula, and the Scotia Arc. These regions comprise a unique and highly significant geologic province in the Antarctic Continent, whose understanding can have far-reaching scientific and, potentially, economic implications. Scattered reconnaissance geology and some paleomagnetic and geochronologic work have already been carried out in this region, but the results are ambiguous, and more work is urgently required to provide a space-time framework for the other geologic studies. There should be a major effort, building on the planned JOIDES drilling in the Bellingshausen and Scotia Seas, to study in a systematic fashion the geologic structure and history of this mobile belt and the surrounding ocean basins. Also, more marine geophysical work is badly needed in the complex southeast Pacific area. This work is secondary to the need for the *Eltanin* to complete her circum-Antarctic circuit, but it is still important.

PRE-ANDEAN OROGENIC BELTS

The current margins of West Antarctica and the Antarctic Peninsula can be related in large part to the present system of spreading ridges, which dates back to Jurassic or early Cretaceous time. Earlier history can be related to geodynamic processes only insofar as the rock record on land can be interpreted. In the case of Antarctica, pre-mid-Mesozoic history is intimately tied to Gondwanaland and the processes affecting its margins. A proper understanding of the orogenic belts crossing Antarctica is essential not only for the interpretation of the geologic history of the continent but also for pinning down the correct arrangement of the separate fragments constituting Gondwanaland.

GONDWANIDE (ELLSWORTH) OROGEN

The Gondwanian orogeny is by far the most important link in any attempt at reconstruction of Gondwanaland in the south Atlantic sector because it was followed shortly by fragmentation of the supercontinent. Elements of the Gondwanide orogen occur in the Ellsworth and Pensacola Mountains and in various parts of the Antarctic Peninsula and the Scotia Arc. Detailed stratigraphic and structural analyses of the rocks of these areas are essential prerequisites to any comprehensive synthesis of Gondwanaland; reassessment of current syntheses will probably be necessary when programs currently under way have been completed and the results published. Further, the enigmatic termination of the Gondwanide orogen against the Andean orogen and the possibility of Gondwanide structures being present in other parts of West Antarctica are problems that have not yet been resolved.

BORCHGREVINK OROGEN

This Middle Paleozoic mobile belt has long been known, but its extension from North Victoria Land into parts of West Antarctica, such as Marie Byrd Land, has yet to be demonstrated.

ROSS OROGEN

The early Paleozoic belt of deformed sediments and associated intrusive rocks along the Transantarctic Mountains appears to define the earliest recognizable orogenic belt marginal to the old cratonic areas of East Antarctica. Studies of parts of this orogen have been completed in several areas;

however, much remains to be done, such as detailed stratigraphic and structural studies on the graywacke-shale sequence of the Goldie Formation and its equivalents and on the archaeocyathid-bearing Cambrian limestones.

The Ross orogen is truncated by the Borchgrevink orogen in north Victoria Land, which is thus an excellent area to study the relations between the two Paleozoic orogens and the old crystalline basement complex. Such studies would also add to our knowledge of the geologic relation between Antarctica and Australia.

RELATIONS BETWEEN EAST AND WEST ANTARCTICA

The crustal structures of West and East Antarctica are known to be grossly different, even from the meager information currently available. The coastal exposures of West Antarctica include Paleozoic rocks that do not conform with any simple pattern of orogenic belts decreasing in age away from the basement complex of East Antarctica. The suggestion has been made that West Antarctica comprises several small crustal blocks that have been rotated relative to each other and to East Antarctica. Whether or not that is true, the differing crustal structures and sparse knowledge of West Antarctic geology demonstrate that the determination of the past and present relationships between East and West Antarctica remains among the fundamental problems of antarctic geology.

WEST ANTARCTIC GEOCHRONOLOGY AND GEOPHYSICS

Petrologic, geochronologic, and paleomagnetic studies of critical areas in West Antarctica are essential for a correct interpretation of geologic history and for determining whether parts of West Antarctica may be crustal blocks welded onto East Antarctica. Since direct studies are necessarily limited by the ice cover, geophysical measurements should also be made. Seismic-refraction profiles more detailed than those obtained during the reconnaissance traverse program are particularly needed to delineate upper crustal structure. Gravity surveys should be carried out wherever large regional gravity anomalies are known to exist, since these probably result from major geologic features of the crust or upper mantle.

THE ROSS EMBAYMENT

One of the most intriguing parts of the Antarctic Continent from the standpoint of its geologic structure is the Byrd subglacial basin. It cannot be considered "typically continental," since it lies far below sea level and its crust is unusually thin, yet it certainly is not oceanic. The "Ross embayment," an extension of the Byrd subglacial basin comprising the Ross Sea and the Ross Ice Shelf, is more suitable for many geophysical investigations than the interior of West Antarctica.

To carry out deep seismic refraction studies reaching Mohorovičić discontinuity, it is highly advantageous to fire explosive charges in water, since the energy coupling is far superior to that of shots in ice. On the other hand, recording conditions are best on "land." Therefore, an ideal arrangement for refraction studies is to record on the Ross Ice Shelf with shots fired in the Ross Sea.

JOIDES drill holes in 1973 penetrated to basement through a thick Cenozoic section in the Ross Sea, so a direct correlation between seismic results and core samples of the upper part of the crustal column is now possible.

Gravity measurements on floating ice are significantly improved over those on grounded ice because no corrections for ice thickness are necessary.

Examination of deep cores from the Ross Sea will give direct evidence of the late Mesozoic and Cenozoic history of Antarctica, which is largely absent in the continental rocks, except in the Antarctic Peninsula.

Heat-flow determination can be made more easily under water than on land.

Due to its accessibility to the support facilities at McMurdo, the Ross embayment is a particularly convenient area in which to carry out aeromagnetic and other airborne surveys.

SURFACE-WAVE-DISPERSION STUDIES

Surface-wave-dispersion analyses already carried out have revealed the fundamental difference in crustal structure between East and West Antarctica, as shown in the 10-km difference in crustal thickness. The study of West Antarctica, however, is still based primarily on the Love-wave group velocities from a single earthquake over a narrow period range between 20 and 30 sec. Although the coverage of East Antarctica is much better, it too, is inadequate. Dispersion analyses are unique in providing information on average earth structure over extensive regions and in being almost completely unhindered by the presence of the ice sheet. Furthermore, they are very inexpensive in terms of both scientific and logistic support funds, since no field program is involved; on the basis of scientific information per dollar, they cannot be equaled. Dispersion studies should therefore be carried out periodically as data accumulate and as knowledge of the structure of the surrounding ocean basins is improved. Long-period seismograph stations currently in existence should be maintained, and new seismographs should be set up wherever possible on bedrock around the antarctic coast to provide additional propagation paths and to permit the determination of travel-time differences across purely continental paths.

4

Active Crustal Movements and Volcanicity

An important part of any study of geodynamics, in the Antarctic as elsewhere, is a search for evidence of presently active crustal movements, both vertical and horizontal. There are several lines of evidence relating to active movement that warrant further investigation.

SEISMICITY

The most direct evidence is the seismicity of the Scotia Arc region. The study of seismicity throughout the world has played an important part in the development of the new global tectonics, and the importance of having accurate focal information has become very clear. High priority should therefore be given to establishment of a sufficient network of seismograph stations around the Scotia Sea to determine accurately the location, origin time, and sense of motion of earthquakes in the region.

The British Antarctic Survey (BAS) is installing permanent seismic stations on the North and South Scotia Ridges, so teleseismic coverage will be reasonably good. However, the BAS stations will not have the capability of monitoring microearthquakes, which have recently been used effectively to determine the motion along particular fault zones. Single-season field programs of microearthquake recording should be sufficient to determine the sense of fault motion in selected areas. Areas particularly recommended are (a) the South Sandwich Islands, where the Americas plate is believed to be subducted beneath the Antarctic plate; and (b) the South Shetland Islands, currently the most active part of the Antarctic continental margin.

VOLCANICITY

Antarctic volcanic activity is related geographically to both active and passive types of continental margins—volcanoes of the South Sandwich

Islands and Deception Island lie in a tectonically active belt, whereas those of Ross Island and Mt. Melbourne are in more stable regions. Late Cenozoic lavas from each type are highly distinctive chemically, which suggests a different depth of origin or degree of contamination during crustal transit. Detailed petrologic examination of the lava types should be carried out in conjunction with seismic monitoring on active volcanoes to determine the focal depths of the tremors associated with magmatic processes. Such studies would make a substantial contribution to our understanding of the development of island arcs at oceanic lithospheric plate boundaries and of the reasons for differences between the volcanic products formed above subduction zones and those formed along passive continental margins.

GRAVITY BASE STATION TIES

A major difficulty in accurate analysis of gravity data throughout Antarctica is the poor knowledge of absolute gravity at antarctic base stations. These base stations should be tied to each other more accurately and to the base station network for the rest of the world. This project does not involve major expense, but it is important not only for antarctic geology and geophysics but for the completion of worldwide gravity coverage. The importance of this is recognized by the International Association of Geodesy, which at the Moscow IUGG General Assembly passed a recommendation that connection of all major antarctic base stations to the international network be made as quickly as possible.

GRAVITY SURVEYS

Gravity surveys to date have indicated that isostatic compensation for the superimposed load of the antarctic ice is at least three fourths complete on a broad regional basis. By means of more precise elevation determinations and electromagnetic sounding for ice thickness measurements, much more accurate analyses of gravity data should be possible in the future. These should permit both the search for deviations of only a few percent from isostatic equilibrium over broad areas and the examination of more restricted areas. Glaciological data suggest that the thickness of the ice sheet may be changing in some places. Such areas, if they can be demonstrated to exist, would be of particular interest for the study of isostatic adjustment. Gravity surveys combined with surface leveling and electromagnetic sounding of ice thickness should therefore be carried out wherever large regional imbalance in the glaciological regime occurs, wherever regional gravity anomalies are known to exist, and in marginal areas where recent retreat or advance of ice is suspected.

ESTABLISHMENT OF TIDE STATIONS AND BENCH MARKS

For determination of eustatic changes in sea level, caused by the isostatic response of the Antarctic Continent to the ice load, and of active tectonic movements, it is important that a network of ocean tide stations be established along the antarctic coast. The establishment of tide stations at a few well-chosen sites and the construction of bench marks accurately tied to the tide stations is part of our present responsibility to the active scientists of 50 years hence. Significant results from the measurements may not be expected for a decade or more, but the stations must be established now for the benefit of future studies.

NONISOSTATIC CRUSTAL UPLIFT

There is direct evidence that vertical crustal movements are not confined to isostatic response. Careful study has shown that recent marine fossils in the dry valleys were deposited *in situ*, indicating a relative uplift of the land of at least 300 m in the last 1 million to 2 million years, a rise too large to be due to isostatic effects alone. Such movements are rapid enough to be susceptible to direct observation by accurate leveling over a period of tens of years. Initial surveys should be carried out as soon as possible.

5

Studies of the Late Cenozoic Environment

The importance of studies of the chronology of glacier variations in Antarctica has been emphasized in two reports of the Committee on Polar Research of the National Research Council [1970, 1974] : *Polar Research: A Survey* and *Antarctic Glaciology: Guidelines for U.S. Program Planning, 1973–1983.* The present report attempts to avoid repetition of the material in *Antarctic Glaciology*, to which reference should therefore be made.

The chief value of these studies lies in two objectives: (a) a knowledge of past glacier variations in Antarctica is required for testing dynamic models designed to predict future changes of the ice cover; and (b) considerations of past glacier variations lead directly to information on climatic variations since the onset of glaciation of the continent. These two objectives are closely interrelated by the complex and dynamic interaction between the antarctic ice sheet and global climate. Several areas in Antarctica that are recommended for particular research emphasis are described in *Antarctic Glaciology: Guidelines for U.S. Program Planning, 1973–1983* [Committee on Polar Research, 1974]. Glacial geology studies also give information on changes in relative sea level, caused both by absolute changes in sea level and by changes in elevation of the bedrock (see Chapter 6).

COMPARATIVE GLACIAL GEOLOGIC CHRONOLOGIES

Because 95 percent of the continent is now covered by ice, the history of former glacier variations can be determined *on land* only in the relatively few ice-free areas whose physiography is suitable for the preservation of glacier-deposited material. In most of these areas, the determinination of an absolute chronology for glacier variations has not yet been possible because of the lack of material for radiocarbon dating (and the antiquity of the variations) and the absence of related volcanic events that might be dated by K–Ar radiometric techniques. In areas of this type that have been investigated so far, only relative chronologies have been established, and it is essential that comparative studies be made of the glacial geology in these areas and in those areas of southern Victoria Land where an outline chronology already exists.

DRILLING BENEATH THE ROSS ICE SHELF

The Ross embayment is extremely important in the study of the Late Cenozoic environment. Because the antarctic ice sheet either calves directly into the ocean or forms floating ice shelves around most of the continent, the most valuable single record of glacier variations on the continent during the Late Cenozoic lies in the sediments of the Continental Shelves and the surrounding deep ocean. Sediment samples were obtained in the Ross Sea in 1973 by the *Glomar Challenger* during Leg 28 of the Deep Sea Drilling Project (DSDP). Further sediment samples will be obtained in McMurdo Sound by the Dry Valley Drilling Project (DVDP). It is thus vitally important that core drilling in the sea floor beneath the Ross Ice Shelf be carried out to as great a depth as possible as part of the Ross Ice Shelf Project. The comparison of the upper parts of the three sets of cores will give valuable information on the sedimentation conditions under an ice shelf, a depositional environment not previously investigated. Combined with geochemical, paleontological, and magnetostratigraphic data, detailed information will be obtained on fluctuations of the Ross Ice Shelf and variations in the degree of glaciation of the continent. Studies of paleomagnetism and K–Ar dating made on volcanic rocks of Ross Island and southern Victoria Land, and of any volcanic rocks found in the cores, will give an absolute time scale to apply to the magnetic stratigraphy of the cores, and hence to the glacier variations.

OCEAN CORE STUDIES

Attention should be paid to analyses of cores obtained from other JOIDES drilling sites in the Southern Ocean for comparison with the cores from the Ross Sea and with those already analyzed from the Weddell Sea. The collection and examination of piston cores from the *Eltanin* have been a source of vital information about the Late Cenozoic environment of the antarctic regions.

6

Special Geological Problems

Past geological studies of Antarctica suggest that future emphasis should be placed on the study of geological processes and the role of Antarctica in unraveling the history of the earth. A few antarctic geological features that are especially significant in their bearing on broader problems are described below.

IGNEOUS PROCESSES

JURASSIC BASALT

Basaltic igneous activity was widespread in the southern hemisphere in mid-Mesozoic time and is commonly believed to have been associated with the breakup of Gondwanaland. The geologic relationships in the igneous intrusions (Ferrar dolerite) and volcanic piles (Kirkpatrick basalt) are much better displayed in Antarctica than on any other continent because of the high relief and fresh exposures offered by the Transantarctic Mountains. Relationships are seen that are available nowhere else. The Dufek intrusion, a layered gabbroic body in the Pensacola Mountains, is the largest of these Jurassic intrusions and is one of the largest known bodies of this type in the world. Similar layered intrusions–the Bushveld of South Africa, the Sudbury of Ontario, and the Stillwater of Montana–contain large reserves of a variety of useful metals, including nickel, copper, platinum, chromium, iron, and vanadium. Detailed study of antarctic igneous bodies will contribute to a better understanding of the mechanics of magma emplacement in the crust, of the relations between intrusive and volcanic activity, and of the complex physicochemical processes by which magmatic ore deposits form and by which magmas differentiate to form rocks varying greatly in composition.

The Ferrar Group in the Ross Sea sector is also part of a unique geochemical province characterized by anomalously high strontium isotopic ratios. Furthermore, there appears to be a correlation between initial ratio and silica content that implies contamination on an unprecedented scale. An understanding of the petrogenesis of these rocks would be a fundamental contribution to geology.

ACTIVE CONTINENTAL MARGIN PROCESSES

The Antarctic Peninsula and Scotia Ridge are apparently disrupted segments of a late Mesozoic to early Cenozoic active continental margin. Dynamic interactions between continental and adjoining oceanic crustal plates led to the development of marginal basins and thick sedimentary and volcanic accumulations, locally strong deformation, and the production and upward emplacement of granitic magma on a large scale. Many of the geologic relationships are very well displayed, and further detailed studies of granitic bodies in this region will lead to a better understanding of the structural development of the southeastern Pacific rim and the role played by granitic magma evolution, intrusion, and volcanism.

PALEONTOLOGY

The fossil record of Antarctica is not extensive, but it does include elements that deserve intensive study because of their wider significance in paleontology. Three will be considered here, but this in no way implies that these are the only faunas or floras deserving attention. For instance, Mesozoic and Cenozoic invertebrates from the Antarctic Peninsula and West Antarctica are important in the circum-Pacific faunas. Continued geologic work will undoubtedly reveal more material that is significant.

VERTEBRATE PALEONTOLOGY

The Triassic amphibians and reptiles recently discovered in the central Transantarctic Mountains provide significant evidence in the paleontological arguments concerning continental drift. As yet, the total fauna is not well known because of the largely reconnaissance nature of the collecting; however, enough is known to establish a close identity at the specific level between some elements of the antarctic fauna and corresponding elements of the *Lystrosaurus* zone of South Africa. On the other hand, there are also elements unrepresented or poorly represented in the South African fauna. These similarities and differences need to be investigated in depth to establish the relation of the antarctic fauna to the *Lystrosaurus* zone fauna of other southern continents and to Lower Triassic faunas of the whole world and to determine its place within the framework of biostratigraphic correlation.

It must also be recognized that further vertebrate faunas are likely to be discovered in the Beacon sequence of the Transantarctic Mountains and that these will also deserve in-depth study, particularly if they come from other parts of the sequence. Finally, discovery of fossil mammals, particularly marsupials in Cenozoic rocks, would provide significant support for biogeographical dispersal patterns recently proposed for the modern Australian fauna.

INVERTEBRATE PALEONTOLOGY

Probably the most significant invertebrate fauna presently known in the Antarctic is that of Upper Cambrian age from the Ellsworth Mountains. This fauna comprises a trilobite–mollusk assemblage, along with archaeocyathids and brachiopods, in which the trilobites provide excellent evidence for an age assignment. This is the only known archaeocyathid-bearing Upper Cambrian locality in the world. Further, the mollusk assemblage is probably the best preserved and most diverse fauna of its age. A unique element in the fauna is the monoplacophorans, one of which may bridge the evolutionary gap to the cephalopods. This fauna can make a very significant contribution to invertebrate paleontology.

PERMIAN AND TRIASSIC FLORAS

The *Glossopteris* and *Dicroidium* floras of the southern continents are characteristic of the Permian and Triassic, respectively. The dominance of one plant renders intercontinental comparative studies of the floras valuable; furthermore, Antarctica has a special role because of the occurrence of the only known autochthonous silicified coal balls from both Permian and Triassic rocks of Gondwanaland. These coal balls contain permineralized and histologically preserved roots, stems, leaves, seeds, spores, and fungi. Their continued study would be a major contribution to paleobotany.

7

Antarctic Mineral Resources

Determination of Antarctica's geological framework is a prerequisite to evaluation of the resource potential of the continent and the surrounding ocean floor. Because of the scarcity of rock outcrops, many features of the framework are poorly, if at all, known. Deep drilling and geophysical studies will play an increasingly important role in understanding the structure of Antarctica, and a number of scientific problems can be resolved only by expensive deep drilling. As exemplified by the finding in 1973 of gaseous hydrocarbons by the *Glomar Challenger* in sediments of the Ross Sea Continental Shelf, scientific drilling may contribute in a direct way to our knowledge of Antarctica's resources.

Knowledge of useful minerals in Antarctica is presently inadequate for accurate assessment of their potential contribution to global resources. Only two materials, a sedimentary iron formation in the southern Prince Charles Mountains and coal beds in the Transantarctic Mountains, are known to be of sufficient size to be classed as mineral "deposits." Neither is presently of economic utility. Many potentially useful materials, such as copper, chromium, gold, and other metals, have been discovered, but all known bodies are of such small size or there are so few quantitative data about them that they can only be classed as mineral "occurrences" and are at present chiefly of scientific interest. Of the known occurrences, the hydrocarbons in the Ross Sea sediments seem to have the highest potential for near-future economic activity because of their accessibility and the greater technological capability for offshore work compared with work on the continent.

During the remaining years of the present Antarctic Treaty, at least, it is important that the U.S. program give realistic but not exaggerated attention to the potential for mineral deposits in Antarctica and that it share such information openly with other nations, in order to encourage other nations to do the same.

8

Priority Ordering

The Panel on Geology and Solid Earth Geophysics has attempted to assess the relative *scientific importance* to the antarctic program of the various projects and research problems identified and has divided them into three priority groups. Priority 1 is based on (a) acquisition of raw data basic to other studies; (b) the need to initiate long-term projects now, rather than some years hence; and (c) evaluation of antarctic geology in the framework of current hypotheses of global significance. Priority 2 is based on (a) studies of particular interest because of their relevance to the science of geology as a whole and (b) studies of the major problems in antarctic geology. Priority 3 is based on studies of interest that are necessary for understanding Antarctica but that have less immediate importance. The listed order within each group has no priority significance.

FIRST PRIORITY

Environmental safeguards and procedures
Topographic mapping
Regional geological and geophysical surveying
Stateside analyses
Radio-echo sounding
Circum-Antarctic marine geophysics by the USNS *Eltanin*
Core drilling into bedrock beneath the ice
New techniques
Active continental margins
Drilling beneath the Ross Ice Shelf
Ocean-core studies
Seismicity
Volcanicity
Establishment of tide stations and bench marks
Nonisostatic crustal uplift

SECOND PRIORITY

Remote sensing

Igneous intrusives of passive continental margins
West Antarctic geochronology and geophysics
The Ross embayment
Comparative glacial geologic chronologies
Special geological problems

THIRD PRIORITY

Special marine geophysical studies
Cratonic geology of passive margins
Pre-Andean orogenic belts
Surface-wave-dispersion studies
Gravity base station ties
Gravity surveys

Recognizing that limitations on funding and logistic support exist, the Panel has also attempted to relate the projects and problems to a logical *time sequence.*

1. Some projects should be completed as soon as possible because of the dependence of other projects upon their completion. These are the following:

Topographic mapping
Regional geological and geophysical surveying
Circum-Antarctic marine geophysics
Radio-echo sounding
Gravity base station ties
Establishment of tide stations and bench marks
Nonisostatic crustal uplift

2. The region of the Ross drainage basin and its margins, from the "90° W Ridge" to the outer continental margin in the Ross Sea, is relatively accessible to current logistic support and is a region in which several major programs are planned for the next several years. A concentrated effort in this geographic area should provide maximum scientific output per dollar expended. We therefore *recommend* that the primary emphasis of the continental program for the next five years be in this region. At the same time, we *recommend* that the current level of support be maintained for work in the Antarctic Peninsula and Scotia Arc areas.

3. In succeeding years, emphasis of the continental program should shift to the study of the Weddell drainage basin east of the "90° W Ridge" and to more extensive work in the Antarctic Peninsula.

9

Special Recommendations

1. R/V *Hero* provides transport for geologic parties in the Antarctic Peninsula/Scotia Arc area that is unique. Only a ship of her type can provide a relatively low-cost base for geologic studies in this area of the Antarctic Continent. It would be a severe blow if she were lost to the antarctic program at a time when the significance of this area for global geodynamics is becoming clear. The alternative appears to be costly icebreaker/helicopter support, which does not have the flexibility of the *Hero* system and which cannot reach the wave-cut platforms below cliffs, where many of the definitive rock exposures are found.

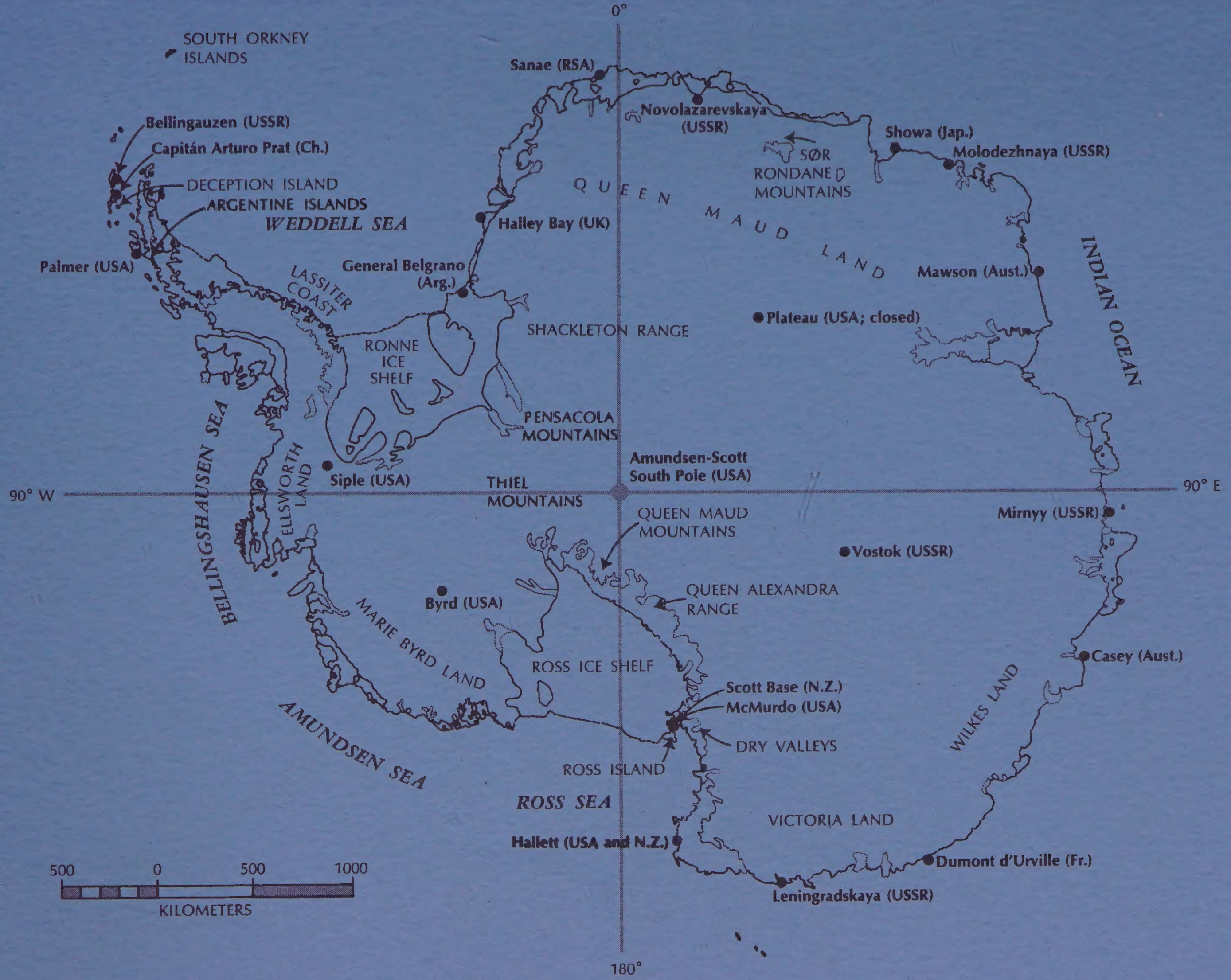
2. The Panel *recommends* that, in the future, detailed geologic maps, when possible, be published at a uniform scale of 1:50,000. Adherence to a uniform scale for future detailed mapping projects would aid in the establishment of a new, standardized geologic map series that could supersede the reconnaissance series when it is completed.

3. The Panel wishes to emphasize the importance of Antarctica to the International Geodynamics Project, the objectives of which are to study the dynamics and dynamic history of the earth, with emphasis on phenomena that affect surface or near-surface processes and structures. This includes investigations related to movements and deformations (past and present) of the lithosphere, relevant properties of the earth's interior, and especially any evidence for motions at depth. As pointed out in the U.S. program proposed by the U.S. Geodynamics Committee, Antarctica offers a unique opportunity to study (a) the evolution of a presently stable plate, (b) the history of certain subduction zones in adjacent plates for which it provides the only reference frame, and (c) the fragmentation of a supercontinent into now widely dispersed parts. The proposed period for the International Geodynamics Project, 1972–1977, has recently been reaffirmed by the International Geodynamics Commission and by the ICSU General Assembly. Thus, if the desirable contribution of antarctic geological and geophysical research to this important international project is to be made, the relevant programs, as outlined in the report of the Panel, must be supported in the next 4 years.

References

Committee on Polar Research, National Research Council. 1970. *Polar Research: A Survey*. National Academy of Sciences, Washington, D.C.

Committee on Polar Research, National Research Council. 1974. *Antarctic Glaciology: Guidelines for U.S. Program Planning, 1973–1983*. National Academy of Sciences, Washington, D.C.



ANTARCTICA Selected Stations and Physical Features

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